An Improved EEG Pattern Classification System Based on Dimensionality Reduction and Classifier Fusion

By

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Certificate

I, Akram Saleh Mousa AlSukker, declare that this thesis titled, An Improved EEG Pattern Classification System Based on Dimensionality Reduction and Classifier Fusion, and the work presented in it are my own. I confirm that:

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- Where any part of this thesis has been previously submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
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Dedication

I would like to dedicate this thesis to my mother and father, Noura and Saleh AlSukker. Throughout my lifetime, they always attempted to instill in me the desire to acquire new knowledge and their words of wisdom are a source of inspiration and strength.

Abstract

Analysis of brain electrical activities (Electroencephalography, EEG) presents a rich source of information that helps in the advancement of affordable and effective biomedical applications such as psychotropic drug research, sleep studies, seizure detection and brain computer interface (BCI). Interpretation and understanding of EEG signal will provide clinicians and physicians with useful information for disease diagnosis and monitoring biological activities. It will also help in creating a new way of communication through brain waves.

This thesis aims to investigate new algorithms for improving pattern recognition systems in two main EEG-based applications. The first application represents a simple Brain Computer Interface (BCI) based on imagined motor tasks, whilst the second one represents an automatic sleep scoring system in intensive care unit. BCI system in general aims to create a non-muscular link between brain and external devices, thus providing a new control scheme that can most benefit the extremely immobilised persons. This link is created by utilizing pattern recognition approach to interpret EEG into device commands. The commands can then be used to control wheelchairs, computers or any other equipment. The second application relates to creating an automatic scoring system through interpreting certain properties of several biomedical signals. Traditionally, sleep specialists record and analyse brain signal using electroencephalogram (EEG), muscle tone (EMG), eye movement (EOG), and other biomedical signals to detect five sleep stages: Rapid Eye Movement (REM), stage 1,... to stage 4. Acquired signals are then scored based on 30 seconds intervals that require manually inspecting one segment at a time for certain properties to interpret sleep stages. The process is time consuming and demands competence. It is thought that an automatic scoring system mimicking sleep expert rules will speed up the process and reduce the cost.

Practicality of any EEG-based system depends upon accuracy and speed. The more accurate and faster classification systems are, the better will be the chance to integrate them in wider range of applications. Thus, the performance of the previous systems is further enhanced using improved feature selection, projection and classification algorithms.

As processing EEG signals requires dealing with multi-dimensional data, there is a need to minimize the dimensionality in order to achieve acceptable performance with less computational cost. The first possible candidate for dimensionality reduction is employed using channel/feature selection approach. Four novel feature selection methods are de-

veloped utilizing genetic algorithms, ant colony, particle swarm and differential evolution optimization. The methods provide fast and accurate implementation in selecting the most informative features/channels that best represent mental tasks. Thus, computational burden of the classifier is kept as light as possible by removing irrelevant and highly redundant features.

As an alternative to dimensionality reduction approach, a novel feature projection method is also introduced. The method maps the original feature set into a small informative subset of features that can best discriminate between the different class. Unlike most existing methods based on discriminant analysis, the proposed method considers fuzzy nature of input measurements in discovering the local manifold structure. It is able to find a projection that can maximize the margin between data points from different classes at each local area while considering the fuzzy nature.

In classification phase, a number of improvements to traditional nearest neighbour classifier (kNN) are introduced. The improvements address kNN weighting scheme limitations. The traditional kNN does not take into account class distribution, importance of each feature, contribution of each neighbour, and the number of instances for each class. The proposed kNN variants are based on improved distance measure and weight optimization using differential evolution. Differential evolution optimizer is utilized to enhance kNN performance through optimizing the metric weights of features, neighbours and classes. Additionally, a Fuzzy kNN variant has also been developed to favour classification of certain classes. This variant may find use in medical examination. An alternative classifier fusion method is introduced that aims to create a set of diverse neural network ensemble. The diversity is enhanced by altering the target output of each network to create a certain amount of bias towards each class. This enables the construction of a set of neural network classifiers that complement each other.

All proposed feature reduction and classification algorithms have been tested and verified on different datasets including EEG (represented by BCIs and sleep scoring problem). The results obtained are very encouraging when comparing with their counterparts found in the literature.

Acronyms and Abbreviations

AAR: Adaptive Auto-Regressive
AASM: American Academy of Sleep Medicine
ACO: Ant Colony Optimization
ACOFUZZY: Fuzzy Ant Colony Optimization
ANOVA: Analysis of Variance
AR: Auto-Regressive
BCI: Brain computer Interface
BIC: Bayesian Information Criterion
BMI: Brain Machine Interface
BPSO: Binary Particle Swarm Optimization
BPSOMI: Mututal Information based Binary Particle Swarm Optimization
BSS: Blind Source Separation
CAT scan: Computerized Axial Tomography scan
*cb*NNE: Class biased Neural Network Ensemble
CSP: Common Spatial Pattern
CT scan: Computerized Tomography scan
CW*k*NN: Class Weighting *k* Nearest Neighbour
CWT: Continuous Wavelet Transform
DE: Differential Evolution
DEFS: Differential Evolution Feature Selection
DFT: Discrete Fourier Transform
DGA: Diverse Genetic Algorithm
DNF: Desired Number of Features
DS*k*NN: Dempster-Shafer *k* Nearest Neighbour
DWT: Discrete Wavelet Transform
EAs: Evolutionary Algorithms
ECG: electrocardiogram
ECoG: Electrocorticogram
EEG: Electroencephalogram
EMG: Electromyogram
EOG: electrooculogram
ERP: Event-Related Potential
ES: Exhaustive Search
EV: Evoked Potential
FCM: Fuzzy C-Means
FDR: Fisher Discrimination Rate
FFT: Fast Fourier Transform
FIS*k*NN: Fuzzy Inference System *k* Nearest Neighbour

fkNN: Fuzzy k Nearest neighbour
FLDA: Fuzzy Linear Discriminant Analysis
fMRI: functional Magnetic Resonance Imaging
FT: Fourier Transform
GA: Genetic Algorithm
GARF: Relative Fitness scaling Genetic Algorithm
HGA: Hybrid Genetic Algorithm
IBPSO: Improved Binary Particle Swarm Optimization
ICA: Independent Component Analysis
ICU: Intensive Care Unit
kNN: k Nearest Neighbour
LDA: Linear Discriminant Analysis
LFDA: Local Fisher Discriminant Analysis
LLE: Locally Linear Embedding
LMS: Least-Mean-Squares
LMV: Local Mean Vector
LPP: Locality Preserving Projections
LSDA: Locality Sensitive Discriminant Analysis
LVQ: Linear Vector Quantization
MEG: Magnetoencephalography
MI: Mututal Information
MIFE: Mutual Information Feature Evaluation
MIFS: Mutual Information Feature selection
mkNN: Modified k Nearest Neighbour
ML: Machine Learning
MLP: Multi-Layer Perception
MRI: Magnetic Resonance Imaging
MSE: Mean Square Error
NCA: Neighbourhood Componants Analysis
ND: Negative Distribution Fator
NIRS: Near-Infrared Spectroscopy
NN: Neural Network
NNE: Neural Network Ensemble
NoS: Number of Evaluated Subsets
NPE: Neighbourhood Preserving Embedding
NREM: Non Rypid Eye Movment
NWkNN: Neighbourhood Weighting k Nearest Neighbour
OLSFDA: Orthogonal Locality Sensitive Fuzzy Discriminant Analysis
PCA: Principal Component Analysis
PD: Positive Distribution Factor

PET: Positron Emission Tomography
PkNN: Pseudo k Nearest Neighbour
PSD: Power Spectral Density
PSG: Polysomnogram
PSO: Particle Swarm Optimization
PTA: Plus Take-Away
R&K: Rechtschaffen and Kales Rules
RBF: Radial Basis Function
REM: Rypid Eye Movment
RLS: Recursive-Least-Squares
ROC: Receiver Operating Characteristics curve
SA: Simulated Annealing
SBS: Sequential Backward Search
SCI: Spinal Cord Injuriy
SCP: Slow Cortical Potentials
sEMG: surface Electromyogram
SFFS: Sequential Forward Floating Search
SFS: Sequential Forward Search
SGA: Simple Genetic Algorithm
SOFM: Self-Organizing Feature Maps
SSVEP: Steady-State Visual Evoked Potentials
STFT: Short-Time Fourier Transform
SVD: Singular Value Decomposition
SVM: Support Vector Machine
SWS: Slow-Wave Sleep
TMS: Transcranial Magnetic Stimulation
TS: Tabu Search
TSP: Travel Saleman Problem
UCI: University of California, Irvine
uLDA: uncorrelated Linear Discriminant Analysis
WGSSE: Within the Generalized Group Sum of Squared Error
wkNN: Weighted k Nearest Neighbour
wm$k$NN: Weighted Modified k Nearest Neighbour
WPD: Wavelet Packet Decomposition
WPT: Wavelet Packet Transform
WT: Wavelet Transform
WTL: Win-Tie-Loss
WVD: Wigner-Ville Distribution

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